Petrography and structural evolution of ophiolitic remnants in the Bellinzona Zone, Southern Steep Belt, Central Alps (CH/I)

by *Max W. Schmidt*[1]

Abstract

Lenses of ultramafic rocks, enclosed in the gneisses of the Bellinzona Zone, are ophiolitic. The ultramafics are harzburgites containing plagiogranite and rodingite dikes. The latter originated from ferrogabbros, from which relicts of Fe-Ti-oxide-domains, clinopyroxene cumulates and the coarse texture are preserved. The peridotite lenses are surrounded by amphibolites, whose geochemistry has MORB characater. Garnet amphibolites, embedded in the banded gneisses, are clearly distinguished from the amphibolites belonging to the peridotite complex by petrography and geochemistry.

The tectonic evolution is divided into following phases: 1. Emplacement of ophiolites in the gneisses of the Bellinzona Zone, boudinage, and generation of S_1 parallel to compositional banding S_0. 2. Intrusion of leucogranite bodies on a scale of 10 to 300 meters. 3. Isoclinal folding F_2. 4. Mesoalpine amphibolite grade metamorphism and intrusion of the Bregaglia Tonalite. 5. Formation of shear zones, F_3 shear folds and lineation L_3 as a result of backfolding. 6. Generation of F_4 shear folds, by superimposition of a backfolding component and a dextral strike slip component, the latter related to displacement at the Insubric Line. 7. A Riedel-shear system, initially formed at greenschist grade, developed from the Insubric Line.

P-T-conditions of mesoalpine metamorphism are calculated to 6.5–8.5 kbar and 690°–730°C, in agreement with intrusion pressure of the Bregaglia Tonalite and garnet-biotite thermometry in the gneisses.

Keywords: Ultramafic rocks, tectonic evolution, geochemistry, ophiolites, Southern Steep Belt, Central Alps.

1. Introduction

The Bellinzona Zone is part of the Central Alpine Steep Belt[2] (MILNES, 1974), which is a zone of steep plunging east-west-striking units. The tectonic correlation (east-west) of the units in the Steep Belt and their origin (Penninic, Austroalpine or in part Southalpine) is still the subject of some debate. East of Bellinzona, the Southern Steep Belt, is divided into three units, all showing increasing intensity of deformation towards the south. These units are from north to south:

(1) The Bellinzona Zone (KNOBLAUCH and REINHARD, 1939), separated from the Penninic Adula nappe in the north by the mesozoic Paina-marble, a dextral strike slip zone (HEITZMANN, 1987a).

(2) The western tail of the Bregaglia Tonalite at its southern margin with the Melirolo Augengneis (WEBER, 1957).

(3) The Tonale Series, consisting mainly of mylonites and fine-grained schists of various origins (CORNELIUS and FURLANI-CORNELIUS, 1930; FUMASOLI, 1974; FISCH, 1989).

At both «ends» of the Southern Steep Belt, large mesozoic ophiolite nappes occur (fig. 1). At the western end, the Antrona Zone and the Zermatt-Saas Fee unit extend along the Monte Rosa root into the Southern Steep Belt, the latter ex-

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[1] Institut für Mineralogie und Petrographie, ETH-Zentrum, CH-8092 Zürich.

[2] The term «root zone» implies genetic relations and should be discarded.

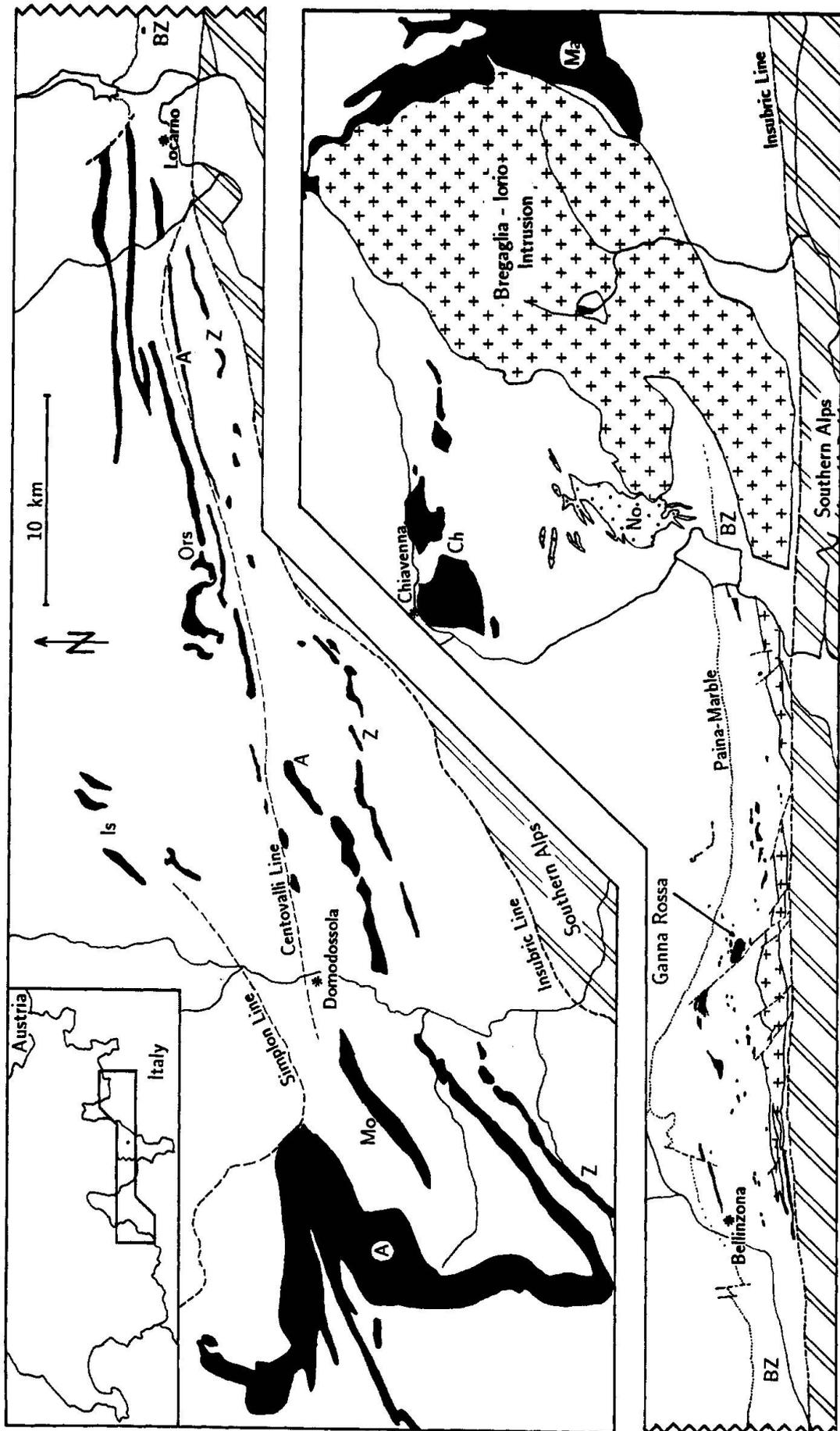*Fig. 1* Major mafic-ultramafic complexes in and near the Southern Steep Belt. Between Locarno and Bellinzona only amphibolites occur, which are not sketched here. Western part modified from COLOMBI and PFEIFER (1986). A: Antrona Zone, BZ: Bellinzona Zone, Is: Isorno Zone, Ma: Malenco unit, Mo: Moncucco, No: Novate granite, Ors: Orselina Zone, Z: Zermatt-Saas Fee unit, Ch: Chiavenna Ultra-mafic body.

tending up to Locarno (PFEIFER et al., 1989; CO-
LOMBI and PFEIFER, 1986). At the eastern end,
the Malenco nappe is separated from the Bellin-
zona Zone by the Bregaglia intrusion. The mis-
sing link between these mesozoic ophiolites is
thought to be located in the Bellinzona Zone (a
common interpretation of mafic-ultramafic com-
plexes in the Bellinzona Zone) - or is perhaps no
longer exposed.

Mafic-ultramafic lenses are also found in the
Berisal nappe, the Bosco Gurin-, Isorno-, Ca-
mughera-Moncucco-, and Orselina Zone, which
are regarded as a major tectonic unit (SCHMIDT,
1908; HUNZIKER, 1966; WIELAND, 1966; MILNES,
1973). The Bellinzona Zone forms the only pos-
sible continuation of the Orselina Zone towards
the west. In the Berisal nappe amphibolites and
hornblendefelses yield ages of 1000 Ma and 500
Ma, respectively (STILLE and TATSUMOTO,
1985). Old ages for amphibolites (1000 Ma) and
ultramafics (500 Ma) from the Isorno Zone and
three amphibolites of the Bellinzona Zone (1000
Ma) have also been determined and have resul-
ted in a model suggesting an old magmatic belt,
extending from the Berisal nappe to the Bellin-
zona Zone (STILLE, 1987).

The purpose of this study is, to estimate the
minimum age (based on structural arguments)
and to determine the origin of the ultramafic len-
ses embedded in the Bellinzona Zone. A secon-
dary goal of this study is to provide supporting
evidence for current work correlating the Bellin-
zona Zone to one of the units discussed above.

The region of investigation (fig. 1) is located
at the eastern side of Val Roggiasca (GR), at the
Swiss-Italian border. It includes the largest ultra-
mafic boudin in the Bellinzona Zone, the Ganna
Rossa (FUMASOLI, 1974). A similar lense at Alpe
Albion, 5 km to the west, was studied by
TROMMSDORFF and EVANS (1974,1979) and
EVANS et al. (1981).

2. Petrography of the peridotite complex

2.1. FIELD RELATIONS

The Ganna Rossa peridotite is a 500 x 1200 m
lens (fig. 2). Although the peridotite is mainly
massive, in the outermost parts of the lens, ens-
tatite forms a foliation parallel to the lens boun-
daries. This foliation may be folded, but due to
the high competence contrast and Riedel-faults
(see chapter 6), the folds are randomly orien-
tated. A steep NNW-plunging lineation, formed
by enstatite, is occasionally present. At the peri-
dotites northern margin there is a 60 m wide
zone of metacarbonates. The peridotite and
metacarbonates are surrounded by banded
amphibolite, 3-20 m in width. The foliation of the
amphibolites is also parallel to the lens bounda-
ries. Boudinaged and foliated rodingite and
plagiogranite dikes are present within the
ultramafic body. The rodingite dikes occur in
swarms, individual dikes are 0.3-1 meter wide
and can be followed over a length of 40 meter.
The plagiogranites appear as a swarm of small
dikes and as a 0.5-2 meter thick dike extending
over a length of almost 100 m. Undeformed gra-
nitic pegmatites and aplites crosscut the perido-
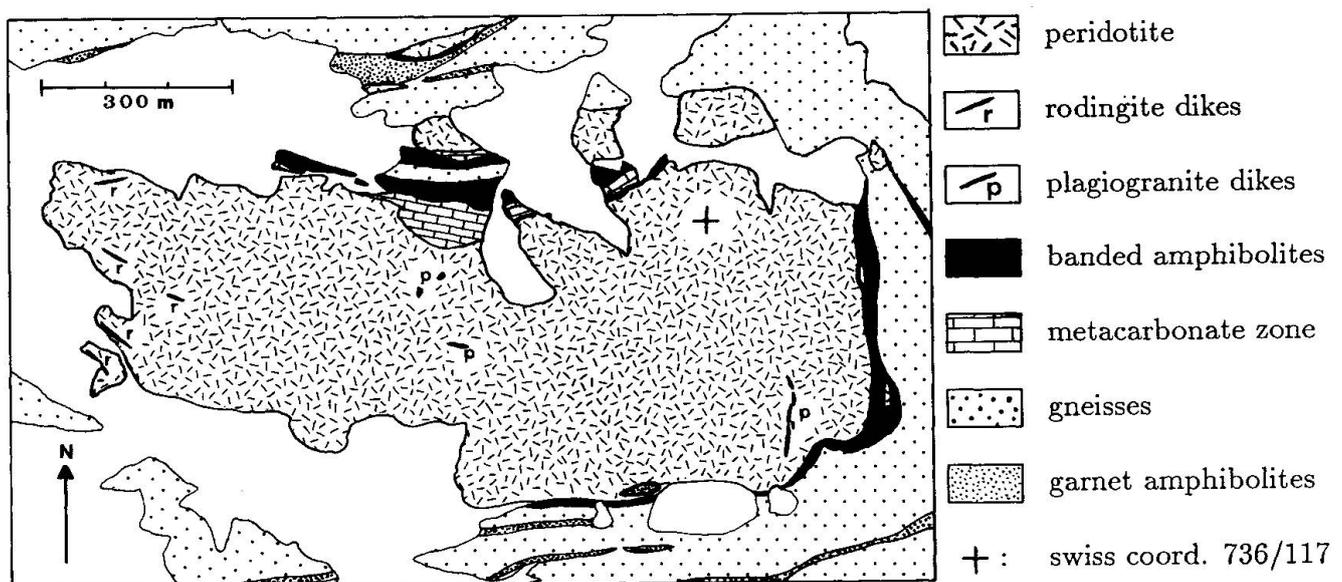tite margin and also occur within the peridotite.

Fig. 2   Geological map of the Ganna Rossa peridotite boudin.

At the contact of the peridotite with the surrounding amphibolites, metasomatism has formed a 1-3 meter wide black-wall. Within the black-wall the peridotite is altered to an actinolite schist and the amphibolite is overgrown by garnet- and plagioclase-bearing biotite schist. The biotite black-wall also sometimes extends into the surrounding gneisses (see chapter 5).

2.2. PERIDOTITE

The ultramafic body is formed by a harzburgite (tab. 1). The metamorphic paragenesis is enstatite-olivine-spinel-clinochlore (EVANS and TROMMSDORFF, 1970; TROMMSDORFF and EVANS, 1974). Inhomogeneities are random, and consist of thin bands of olivine, enstatite or spinel + olivine. Some enstatites show dirty, often broken cores which are surrounded by a clear rim (X_{Mg} = 0.92–0.93). Enstatite plus olivine (X_{Mg} = 0.92–0.94) form a polygonal groundmass containing flakes of clinochlore ($Mg_{4.6}Fe_{0.5}Al_{1.8}Si_{3.1}O_{10}(OH)_8$). Opaque chromian magnetite (Y_{Cr} <0.12, Y_{Al}<0.03), exsolving green spinel (Y_{Al} = 0.82, Y_{Cr} = 0.11), is partly resorbed by the silicate phases. The enstatite cores and chromian magnetites are relicts of pre-mesoalpine stages. Greenish brown or brown chromian spinel (Y_{Al}≈0.7, Y_{Cr}≈0.2) are idiomorphic, uncorroded grains, they are part of the stable mesoalpine metamorphic paragenesis (EVANS and FROST, 1975). Idioblastic tremolite was formed near rodingite dikes as result of Ca-transport back into the peridotite.

Two types of late, nearly undeformed, 10 to 50 cm wide veins (PFEIFER, 1987) crosscut the internal structures and dikes of the peridotite body. One vein-type consists of large crystals (up to 15 cm across) of enstatite, anthophyllite, and talc ± clinochlore ± magnesite. The other kind of vein is formed by clinochlore with idioblasts of enstatite or tremolite.

2.3. GABBRO-RODINGITES

The Ganna Rossa metarodingites are complex in mineralogy but easily recognized as former ferrogabbros. Several mineralogic domain types (garnet domains, vesuvianite domains and Fe-Ti-domains [15 rock-Vol.%]), inherited from an inhomogeneous gabbroic texture, are surrounded by a fine-grained greenish-yellow matrix, mostly composed of fassaite. All domain types are on the scale of 0.5 x 1.5 to 3 x 10 cm and are orientated in foliation planes discordant to the dike strike directions. In addition, coarse-grained diopside is accumulated (≈30 rock-Vol.%) in distinct zones of variable extent on the order of decameter.

A black-wall consisting of several zones, composed of hornblende, green spinel, chlorite, enstatite, olivine and tremolite, separates the rodingite from the peridotite. The present black-wall minerals crystallized post-kinematically and a slight deformation is sporadically observed.

Silicate domains and matrix

The nearly monomineralic garnet domains ($Gros_{.63}Py_{.03}Andr_{.34}$) and vesuvianite domains are interpreted as former plagioclase domains of the gabbroic protolith (TROMMSDORFF and EVANS, 1979). The macroscopic texture has no equivalent on a microscopic scale, the fabric is polygonal in both the matrix and the different domain types. Garnet never appears near dike margins, where chlorite overgrows the rodingite, as result of reactions during metasomatism of the black-wall. The fine-grained matrix consists of the paragenesis fassaite (80%) ($Fas_{30}Dp_{70}$–$Fas_{45}Dp_{55})^3$, grossular, vesuvianite, clinozoisite ± clintonite ± chlorite. Within the matrix vesuvianite-, clinozoisite- and fassaite-porphyroblasts are found, the latter clearly distinguished from diopsides by chemistry and the lack of exsolution and twinning. Clintonite never occurs with vesuvianite or clinozoisite.

Fe-Ti-domains

Fe-Ti-domains consist of a Fe-Ti-oxide core, which has exsolved to lamellae of magnetite-ulvospinel and ilmenite-hematite solid solutions. Exsolution of granular green spinel and rutile also has taken place. The Fe-Ti-oxide cores are rimmed by perovskite or sphene. Exsolution temperatures calculated in the Fe-Ti-oxide cores by use of the two-oxide-thermometer (BUDDINGTON and LINDSLEY, 1964; FROST, 1988) are in the range of 720°C to 820°C and believed to be the result of partial reequilibration from the intrusive temperature during metamorphism.

In several distinct mylonitized zones, Fe-Ti-oxides reacted to either sphene, including rutile ± magnetite ± hoegbomite (former green spinel) ± perovskite, or Ti-garnet + perovskite + Ti-free magnetite. In the mylonite zones titanium was mobile and garnet (max. 12 wt% TiO_2) and vesuvianite (max. 5 wt% TiO_2) adjacent to the Fe-Ti-domains recrystallized with strong Ti- and Fe-gradients, green spinel transformed to hoegbom-

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[3] $Dp = CaMgSi_2O_6$, Fas = Fassaite = CaTs-pyroxene = $Ca(Fe^{3+},Al)^{VI}Al^{IV}SiO_6$

ite. Partial recrystallization also took place throughout the remainder of the mylonite zone at amphibolite grade conditions, this implies that the deformation must be pre- or syn-mesoalpine.

Diopside cumulates

The large diopside crystals (<2 cm) show twinning parallel to (010) and exsolution of magnetite and yellow Ti-garnet parallel to (100) and (010). Probably these diopsides are former magmatic augites. A first deformation kinked the diopside and sometimes the kinkbands have recrystallized as fassaite. Fassaite also corroded diopside grains. In or near mylonitic zones, kinkbands are completely recrystallized as Ti-garnet. A second deformation broke the diopside, at dike margins these extension cracks are filled with chlorite.

2.4. PLAGIOGRANITE

Plagiogranites are mostly associated with ferrogabbros and are indicators for oceanic crustal environments (OHNENSTETTER and OHNENSTETTER, 1980). These authors regard both as high-differentiated residual magmas. The plagiogranite dikes (fig. 2, tab. 1) are leucodiorites, composed of more than 90% plagioclase (An_{29-34}), biotite and muscovite. Alkalifeldspar is random, rutile, zircon, apatite and quartz are accessories. The muscovite present replaces biotite, also biotite is sometimes rimed by fibrolite. In several zones, in which plagioclase is seritizated, biotite reacted to chlorite + epidote.

2.5. METACARBONATE ZONE

The metacarbonate zone is formed by massive calcite-olivine ± diopside ± cummingtonite-rocks, tremolite-olivine-schists, and olivine-enstatite-tremolite-schists, latter representing peridotite relicts enclosed and metasomatised by the metacarbonates. Original structures are not preserved, the severe deformation has formed bands and boudins of these rocks. Because both metacarbonates and peridotite are enclosed by the amphibolites, a primary contact is probable and an ophicarbonate interpretation is plausible, although not conclusive.

2.6. AMPHIBOLITES

Peridotite lenses in the Bellinzona Zone are surrounded mostly by banded amphibolites up to 50 m in width (KNOBLAUCH et al., 1939; FUMA-

SOLI, 1974; HEITZMANN, 1975). This amphibolite hull is part of the boudins. The texture of the amphibolites varies from fine-grained types, interpreted as former basalts (most abundant), to coarse-grained inhomogeneous rocks, interpreted as former gabbros. The latter also occur as dikes in the metabasalts. Major minerals are pargasite and plagioclase (An_{56}^{core}-An_{68}^{rim}), accessories are rutile, ilmenite, magnetite, and sphene. The fabric is polygonal. Retrograde formation of poikiloblastic epidote, accompanied by plagioclase rims (An_{43}-An_{54}), is common. Comparison with garnet-amphibolites in the gneisses (fig. 2) demonstrates their different character (see also WEBER, 1957; p. 281 f.). In the garnet-amphibolites amphibole is hastingsite, garnet is a major component, quartz and biotite are minor components, and clinopyroxene is also present.

3. Amphibolite bulk rock composition

Major and trace element analyses of 30 amphibolites and 12 garnet-amphibolites were made; representative bulk compositions are listed in tab. 1. Three groups are distinguishable: The garnet-amphibolites are low in CaO, Al_2O_3 and MgO, but high in FeO_{tot}, and therefore show higher FeO/MgO ratios than the banded amphibolites. A gabbroic and a basaltic group - as expected by textural features - comprise the two other groups and can be separated within the banded suite. In the discrimination diagrams, the metabasalts of the banded suite plot into the MORB-field (fig. 3-5). The garnet amphibolites are clearly distinguished (especially concerning Ni, Cr, V, Sc, Ba), but not clearly attached to any basalt type by element discrimination. Na, K, Rb and Sr are not useful due to the slight alteration during evolution.

4. P-T-conditions of the meso-Alpine metamorphism[4]

The minerals, which are involved in the reactions described here, are approximately post-kinematik, and show only slight local deformation.

Endmember reactions in the peridotite and rodingites permit estimation of the temperature limits during mesoalpine metamorphism (fig. 6a). The breakdown reaction of chlorite (720° ± 30°C) in the peridotite-rodingite black-wall, and garnet-biotite thermometry (700° ± 30°C) in the

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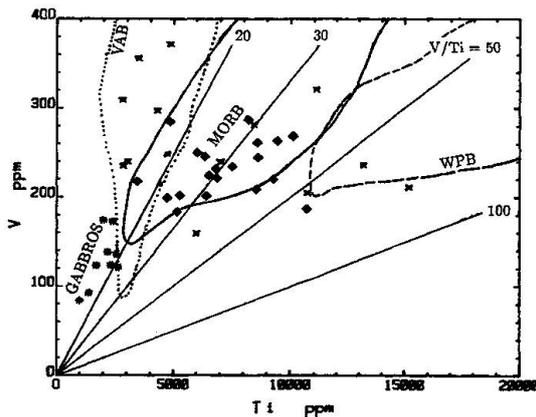
[4]For details see SCHMIDT (1988).

Fig. 3 V versus Ti diagram (SHERVAIS, 1982), modified according to BERTRAND et al. (1987). Fields are: CAB = Calc-Alcaline Basalts, MORB = Mid Ocean Ridge Basalts, WPB = Within Plate Basalts. Fine grained banded amphibolites sourrounding the peridotite (◆) are in the MORB field, garnet amphibolites (x) plot disperse. (✳) = Coarse-grained banded amphibolites.
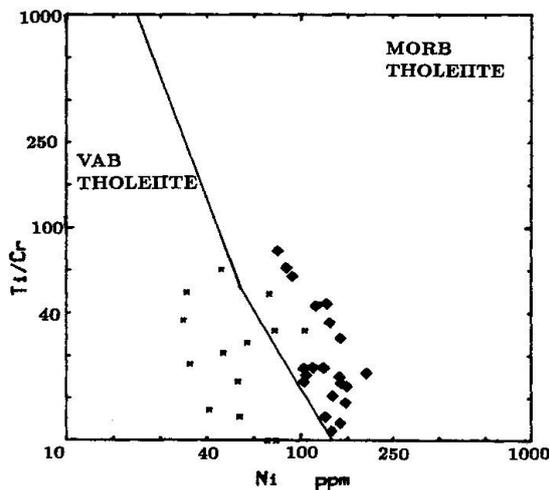

Fig. 4 Ti/Cr versus Ni diagram (BECCALUVA et al., 1979), VAB = Volcanic Arc Basalts, Amphibolites sourrounding the peridotite (◆) are clearly distinguished from garnet-amphibolites (x).
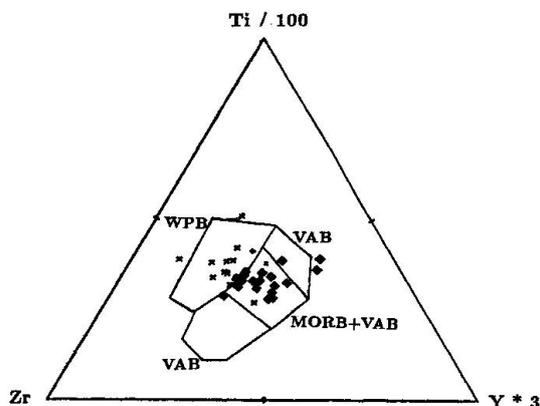

Fig. 5 Ti-Zr-Y-diagram (PEARCE and CANN, 1973). Amphibolites sourrounding the peridotite (◆) plot into the MORB field, garnet amphibolites (x) tend into the WPB field, bur are widespread.

peridotite-amphibolite black-wall, define peak conditions of metamorphism between 690° and 730°C (fig. 6b). In the peridotite-amphibolite black-wall garnets exhibit parallel to {110} a distinct inner zone rich in inclusions of plagioclase, quartz and fibrolite. Barometry (GHENT, 1976; KOZIOL and NEWTON, 1988) results in a pressure of 6.1 ± 1 kbar (Bt-gar → 650°C). This pressure was almost certainly exceeded during metamorphism. To estimate maximum pressure, the appearance of sillimanite ± kyanite is used. Kyanite is reported by KNOBLAUCH and REINHARD (1939; p. 55) in the NW-part of Bellinzona Zone and by WEBER (1957). Kyanite occurs neither in the Ialian part (FUMASOLI, 1974) nor in the southern part (BÜHL, 1980, 1981; this investigation) of the Bellinzona Zone. Probably, a maximum pressure near 8 kbar is a reasonable assumption. Evidence for an earlier high pressure eclogite stage at the Ganna Rossa, as reported by FUMASOLI (1974, p. 131), has not been found.

These results are in good agreement with previous published work. BÜHL (1981) determined 690°C in the gneisses by garnet-biotite thermometry and REUSSER (1987) calculated the intrusion pressure of the tonalite as 7.5 ± 1 kbar by use of the Al-in-hornblende geobarometer (HAMMARSTROM and ZEN, 1986).

Although these conditions would be sufficient to form a substantial amount of melt in acidic rocks, it is not conclusive, that the leucogranites and migmatites present in the surrounding of the Ganna Rossa were originally generated during mesoalpine metamorphism.

5. Petrography of the peridotite surroundings

The Bellinzona Zone is a banded series consisting of gneisses, garnet amphibolites, calc-silicates and marbles, metapelitic schists, migmatites, leucogranitic masses and dikes, and the peridotites and related banded amphibolites discussed above. The gneisses are divided into three main groups (FUMASOLI, 1974; BÜHL, 1980): (1) Plagioclase-gneisses with plag, qz, bt as major components and minor gar, K-spar, amph; (2) Sillimanite-gneisses with plag, qz, bt, and with minor sill, gar, K-spar; (3) Alkalifeldspar-gneisses with K-spar, plag, qz and with minor bt, musc, gar, ± sill. These groups are defined for mapping, continuous transitions to garnet-amphibolites or pelitic schists and between the groups themselves are common.

Rock types generated by melt processes are widespread and important for the determination of relative age relationships. Their petrography is
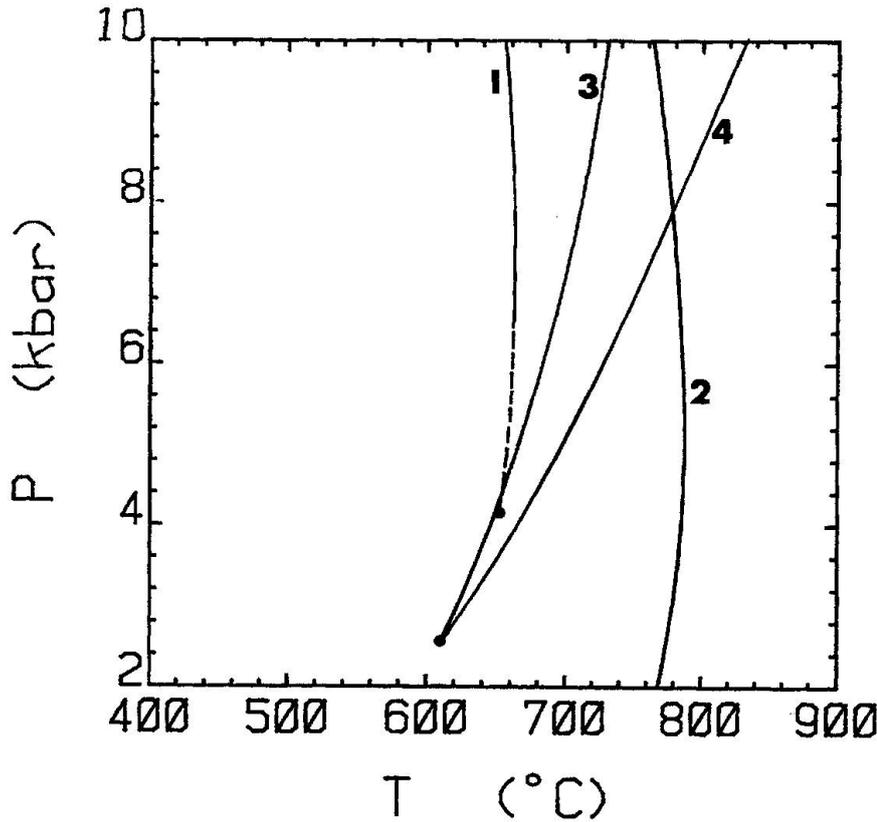
Fig. 6a P-T-diagram showing the equilibria (1) talc + forsterite = enstatite + H_2O; (2) forsterite + tremolite = enstatite + diopside + H_2O in the peridotite and (3) garnet + chlorite = diopside + spinel + H_2O; (4) zoisite + chlorite = anorthite + diopside + spinel + H_2O in the rodingites (equilibria [3] and [4] of RICE, 1983). Reactions (1) and (3) define lower limits of mesoalpine metamorphism.
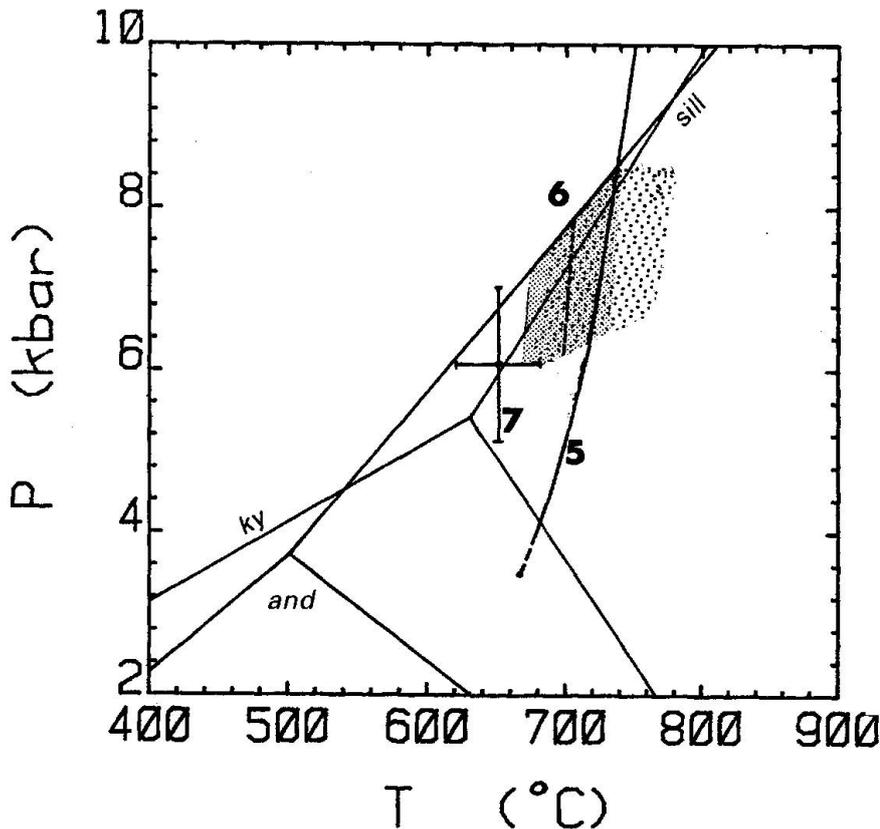
Fig. 6b P-T-diagram showing the equilibrium conditions for: (5) chlorite = enstatite + forsterite + spinel + H_2O (JENKINS and CHERNOSKY, 1985) in peridotite-rodingite black-walls, coarse stippled area represents uncertainty; (6) garnet-biotite-thermometry (calibration of THOMPSON, 1975), fine stippled area represents uncertainty; (7) anorthite = grossular + sillimanite + quartz (NEWTON and HASSELTON, 1980) in the peridotite-amphibolite black-wall. Equilibrium pressure of (7) is the minimum metamorphic pressure. The upper pressure limit is given by sillimanite = kyanite, Al_2SiO_5 phase boundaries from RICHARDSON et al. (1969) and HOLDAWAY (1971). Dark area represents estimated peak conditions of mesoalpine metamorphism.

Tab. 1 XRF-analysis of peridotite, amphibolites, plagioclasite and granite. Method described in Nisbet et al. (1979).

	peridotite	plagioclasite	banded amphibolites coarse-	banded amphibolites fine-grained		garnet amphibolites		leucogranite
SiO_2 (wt %)	39.66	57.95	50.19	44.79	42.96	48.05	48.48	75.50
TiO_2	0.04	0.32	0.18	1.07	1.53	2.31	1.31	0.18
Al_2O_3	1.82	24.25	18.48	17.38	17.48	14.76	15.49	13.30
Fe_2O_3	3.27	1.50*	4.20*	10.10*	10.14*	13.34*	11.20*	1.37*
FeO	5.10	—	—	—	—	—	—	—
MnO	0.12	0.01	0.08	0.24	0.16	0.15	0.22	0.00
MgO	40.12	0.72	10.15	8.82	9.13	5.64	5.76	0.00
CaO	0.15	6.01	12.17	14.58	13.82	11.63	11.82	0.93
Na_2O	0.00	7.41	1.85	0.94	1.97	1.27	3.05	2.10
K_2O	0.00	1.15	0.41	0.09	0.30	0.64	0.66	6.23
P_2O_5	0.03	0.14	0.03	0.09	0.20	0.34	0.18	0.09
H_2O	**8.20	**0.69	**0.39	**0.91	**0.86	**0.49	**0.41	**0.25
	99.23	100.15	98.28	99.08	98.61	98.64	98.61	99.95
Ba (ppm)	32	421	<10	<10	<10	73	66	425
Rb	11	32	12	<8	<8	<8	<8	203
Sr	379	1145	313	375	316	775	251	98
Pb	<5	<5	<5	<5	<5	<5	<5	28
Th	<5	<5	<5	<5	<5	<5	<5	27
Nb	<4	<4	<4	<4	<4	12	<4	<4
La	<20	<20	<20	<20	<20	<20	<20	29
Ce	<15	<15	<15	<15	<15	44	<15	82
Nd	<25	<25	<25	<25	<25	<25	<25	29
Y	7	<3	<3	23	14	12	16	26
Zr	14	221	<10	61	91	167	86	144
V	302	21	83	248	243	264	254	<10
Cr	2581	<6	851	384	390	132	226	<6
Ni	2122	<3	284	133	100	71	76	<3
Co	41	6	18	43	54	91	47	19
Cu	<3	16	<3	<3	<3	<3	6	<3
Zn	67	7	19	74	50	134	85	11
Ga	8	23	3	9	<2	<2	<2	11
Sc	43	<2	26	35	42	29	39	2

* total Fe as Fe_2O_3, ** loss on ignition. U<10, S<50 ppm.

similar to that of the alkalifeldspar-gneisses. They are recognized as intrusives by their discordant contacts, and classified by textural criteria: Small lenticular migmatites (type B; Bühl, 1980) which did not migrate, occur as lenses of a few centimeters in extent in lithologies rich in biotite. Migmatites (type A), on the scale of 1 to 20 meters in length, include xenoliths of gneiss. Leucogranitic bodies (tab. 1), from 20–300 m are also discordant and also contain xenoliths. Granitic aplites and pegmatites show different degrees of deformation. The intensity of which varies from concordant dikes with strong foliation, which were folded by F_2, to highly discordant, nearly undeformed dikes.

6. Structures

Detailed mapping (1:1000) in an area (fig. 1) polished by glaciers, situated south of the Ganna Rossa, but north of the tonalite (around swiss coordinate 735/116) and a profile along the swiss-italian border-crest through the Bellinzona Zone from Paina Marble (Bocetta di Paina) to the tonalite, are the fundamental field work done for this part of the investigation.

The earliest deformation (D_1) preserved, produced a schistosity (S_1) parallel to compositional banding (S_0). S_1 (fig. 7a) is the dominant EW-striking, steep N-plunging foliation of the Bellinzona Zone, characteristic of the Steep Belt. A
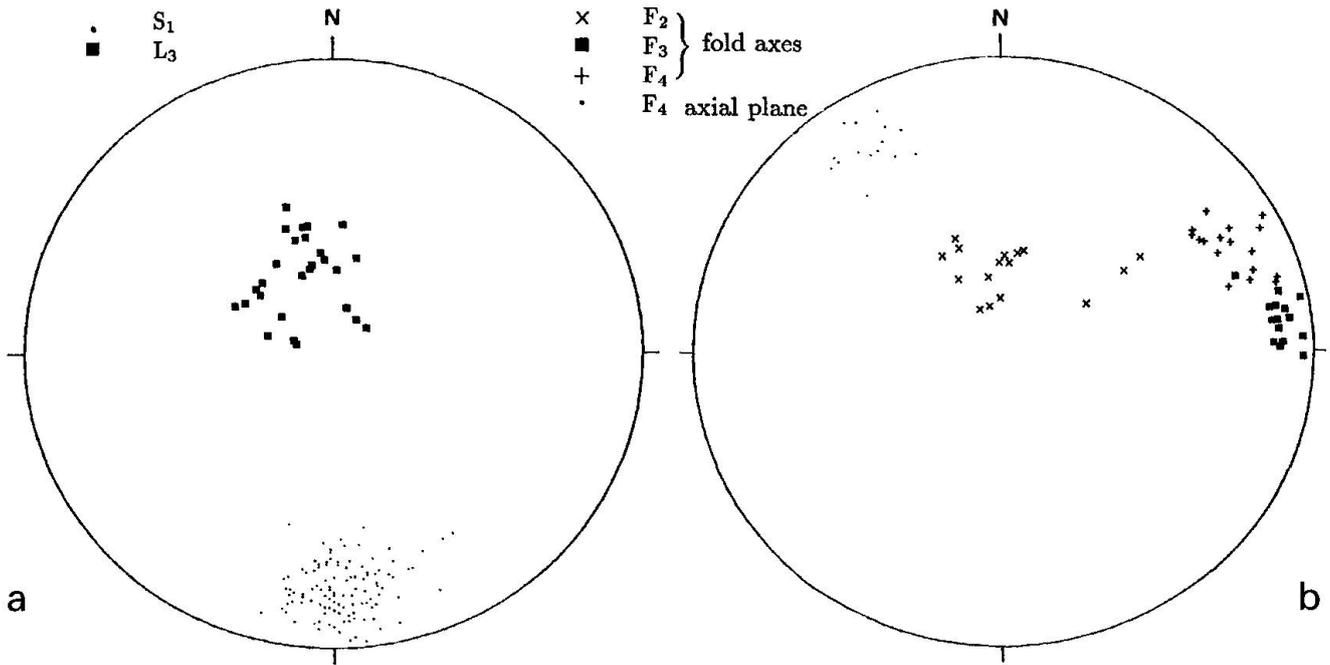
Fig. 7 (a) Stereoplot of S_1-poles and L_3 (lower hemisphere). (b) F_2, F_3 and F_4 fold axis; F_4 axial plane poles. F_3-axis and L_3 are perpendicular.

deviation of S_1 from this orientation is observed near peridotite boudins, where S_1 follows the boudin boundaries, therefore D_1 was responsible for boudinage of the peridotites.

Following D_1 the leucogranites and type A migmatites intruded. They extend parallel to S_1 and are folded by F_2-F_4 and show an intensive S_2 schistosity, but their contacts are discordant. The leucogranites include xenoliths of gneisses and garnet amphibolites showing S_1 (fig. 8).

Deformation D_2 generated isoclinal folds (F_2) (fig. 9) with steep N-plunging fold axes and axial planes parallel to S_1 (fig. 7b). Consequently, S_2 is

only observed in F_2 fold hinges and in the leucogranites and type A migmatites. On a microscopic scale, signs of mineral deformation are not preserved. The fabric in hinges and limbs of F_2 is polygonal.

In 2-10 m wide shear zones parallel to S_1 (fig. 10), tight F_3 shearfolds were formed. The F_3 fold axes are subhorizontal (fig. 7b) and the axial planes subvertical, only one vergence exists (fig. 10). Fabric indicates amphibolite grade conditions. All minerals in F_3 fold hinges are elongated parallel to S_3 and grain boundaries are lobate, as result of recrystallization. A stretching
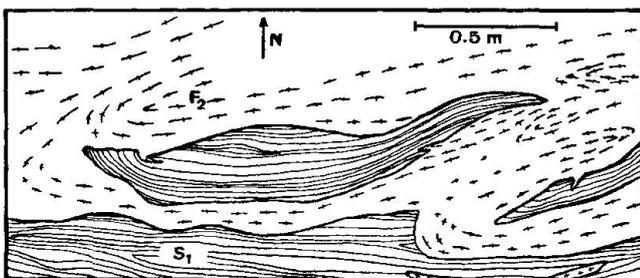

Fig. 8 Xenolith of gneiss, showing S_1, within a leucogranite intruding into the gneisses. The leucogranite is folded by F_2.
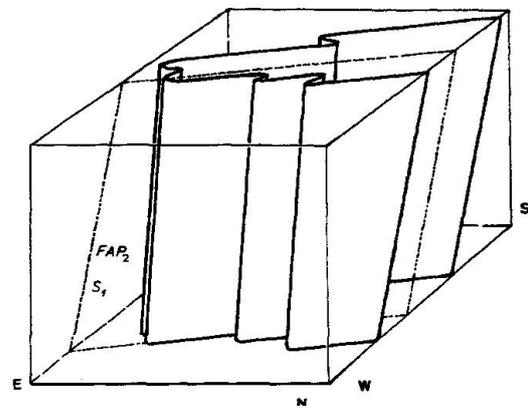

Fig. 9 Block diagram of isoclinal F_2 folds, amplitude 0.5-5 m. Axial plane (FAP$_2$) and S_2 are parallel to S_1.
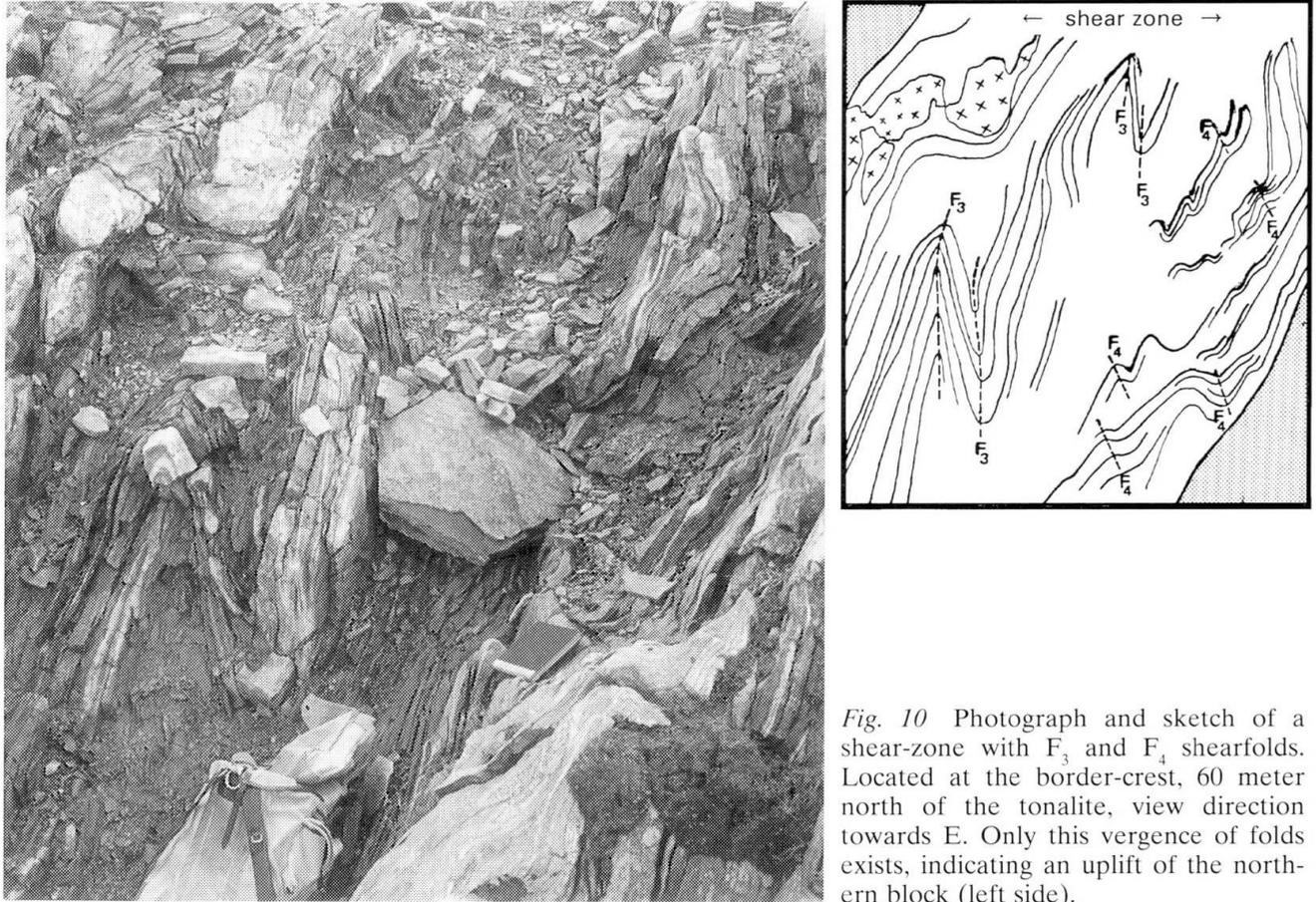
Fig. 10 Photograph and sketch of a shear-zone with F_3 and F_4 shearfolds. Located at the border-crest, 60 meter north of the tonalite, view direction towards E. Only this vergence of folds exists, indicating an uplift of the northern block (left side).

lineation[5] (fig. 7a) is abundant in shear zones and rarely found beyond them. The lineation is perpendicular to F_3 fold axes and not folded by F_3. Therefore, the recrystallization of minerals in F_3 hinges and the orientation of minerals into the lineation L_3 was probably contemporaneous. F_3 and L_3 indicate a north-south directed subvertical uplift of the northern block.

Primarily in the same shear zones, a second generation of shear folds (F_4) was formed. The fold style is open (fig. 10) with a fold axes dip of 20-30° east and the axial plunge 55-70° south (fig. 7b). Elongated minerals are kinked and folded. They remain orientated in the folded S_1 with only minor recrystallization indicating greenschist grade conditions. The movement related to F_4 is a south-directed uplift of the northern block combined with a dextral strike slip component (fig. 11).

Approximately NE-SW oriented dextral faults (fig. 1) and NW-SE oriented sinistral faults (only observed on a cm- to dm-scale) are part of a Riedel-shear system (RIEDEL, 1929) resulting

from the dextral strike slip at the Insubric Line (FUMASOLI, 1974). Initially garnet-amphibolite bands were faulted (with displacement of a few centimeters), while sourrounding gneisses remained ductile. At faults with minor displacement (on the scale of a few meters) flexures are observed. Faults with larger displacement (on a scale of tens to hundreds of meters) form cataclastic zone 1-10 m width.
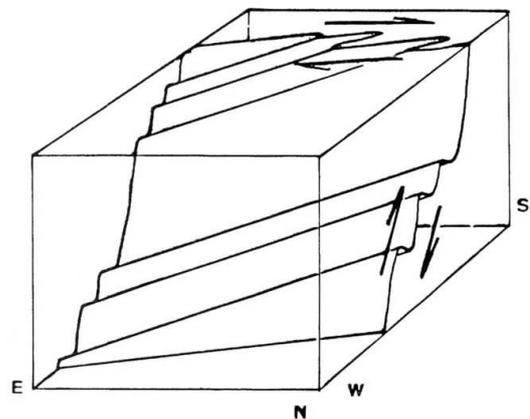

Fig. 11 Block-diagram of F_4 shearfolds. The movement is compound by a backfolding vector and a dextral strike-slip vector. Amplitude $\approx$ 30 cm.

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[5] Which is in general agreement with HEITZMANN, 1987b, fig. 2.

7. Discussion

The tectonic setting of the peridotite-complex is well defined. Peridotite, ferrogabbro, plagiogranite and MOR-basalts prove oceanic origin. The harzburgitic character of the peridotite may be original or the effect of Ca-depletion coeval with serpentinization during rodingitization of the ferrogabbros (TROMMSDORFF and EVANS, 1979). After the intrusion and rodingitization of the ferrogabbro dikes, strong deformation flattened the domains and kinked diopside grains. Subsequent amphibolite grade metamorphism resulted in an equilibrated fabric and mantelling of Fe-Ti-oxide domains with perovskite or sphene. Mylonitization took place in distinct zones, followed by mesoalpine-metamorphic recrystallization which is well documented near Fe-Ti-domains.

A correlation of the structural and metamorphic phases within the peridotite and the peridotite surrounding suggests the following succession of phases: 1. The emplacement of the ophiolite slices into the gneisses ended with their boudinage caused by D_1. Probably the macroscopic schistosity was also produced by this deformation. 2. After D_1, the leucogranites and type A migmatites intruded. 3. D_2 folded the peridotite, the leucogranites, type A migmatites, and gneisses. The polygonal fabric in F_2 folds suggests, that the mesoalpine metamorphism postdated or outlasted deformation D_2. 4. During the mesoalpine metamorphism (38 Ma [JÄGER, 1973] and/or 26 Ma [DEUTSCH and STEIGER, 1985] for discussion see HURFORD, 1986) the Bregaglia Tonalite (30 Ma, GULSON and KROGH, 1973) intruded. The northern contact of the tonalite is tectonic (WEBER, 1957), but there is no evidence for major displacement. 5 + 6. Shearfolds F_3 and lineation L_3, which is parallel to the stretching lineation in the tonalite (FUMASOLI, 1974; FISCH, 1989), indicate a north-south directed uplift of the Central Alps, the well-known backfolding which started before 23 Ma (HURFORD, 1986; SCHMID et al., 1989). Shearfolds F_4 comprise an additional dextral strike slip component. This sequence of late tectonic movements, in the area studied, fit well into the model presented by SCHMID et al. (1987, 1989): Amphibolite grade backfolding – postdating the Bregaglia Tonalite – gradually pass over into a strike slip movement. 7. *Major strike slip movement is located in the Paina Marble, the Tonale Series, and the Tonale Line, but not in the Bellinzona Zone.* The horizontal temperature gradient, resulting from rapid uplift of the Central Alps, is documented by the char-

acter of the Riedel shearing. Within the Bellinzona Zone this shearing initially formed at the transition from ductile to brittle behaviour. Near the Tonale Line only brittle deformation is reported (FUMASOLI, 1974).

The minimum age of the slices of oceanic crust, embedded in the Bellinzona Zone, is deduced from structural relations. The ophiolite emplacement is postdated by the intrusion of leucogranites. Pre- od syn-meso-Alpine F_2 folding postdates the formation of leucogranites and migmatites, and exclude a neo-Alpine origin for the leucogranites and type A migmatites (contrary to the neo-Alpine origin of the Novate granite). As far as known, isotopic ages from highly deformed granites in the mesoalpine gneisses are older than alpine. Analogously, a prealpine age for the of leucogranites, highly deformed migmatites, and highly deformed granitic dikes of the Bellinzona Zone is plausible. Consequently, the ophiolites would be at the *youngest* variscan in age.

This supports the model of STILLE (1987) and excludes a correlation with other alpine ophiolites.

References

BECCALUVA, L., OHNENSTETTER, D., OHNENSTETTER, M. (1979): Geochemical discrimination between ocean-floor and island arc tholeiites - application to some ophiolites. Can. J. Earth Sci. 16, 1874-1882.

BERTRAND, J., DIETRICH, V., NIEVERGELT, P., VUAGNAT, M. (1987): Comparative major and trace element geochemistry of gabbroic and volcanic rock sequences, Montgenèvre ophiolite, Western Alps. Schweiz. Mineral. Petrogr. Mitt. 67, 147-169.

BUDDINGTON, C.W. and LINDSLEY, D.H. (1964): Iron-titanium oxide minerals and synthetic equivalents. J. Petrol. 5, 310-357.

BÜHL, H. (1980): Petrographie, Metamorphose und Strukturen in der Zone von Bellinzona im Gebiet des Corno di Gesero (GR/TI). Diploma thesis Nr. 264. Geol. Inst. ETH Zürich.

BÜHL, H. (1981): Zur Sillimanitbildung in den Gneisen der Zone von Bellinzona. Schweiz. Mineral. Petrogr. Mitt. 61, 275-295.

COLOMBI, A. (1988): Métamorphose et géochimie des roches mafiques des Alpes Ouest-centrales (Géoprofil Viège-Domodossola-Locarno). Ph. D. thesis, Univ. Lausanne, 195 p.

COLOMBI, A. and PFEIFER, H.R. (1986): Ferrogabbroic and basaltic meta-eclogites from the Antrona mafic-ultramafic complex and the Centovalli-Locarno region (Italy and Southern Switzerland) - first results. Schweiz. Mineral. Petrogr. Mitt. 66, 99-110.

CORNELIUS, H.P. and FURLANI-CORNELIUS, M. (1930): Die Insubrische Linie vom Tessin bis zum Tonalepass. Denkschr. Österr. Akad. wiss. math. Kl. 102, 207-301.

DEUTSCH, A. and STEIGER, R.H. (1985): Hornblende K/Ar ages and the climax of Tertiary metamorphism in the lepontine Alps (South Central Switzerland): an old problem reassessed. Earth Planet. Sci Lett. 72, 175-189.

EVANS, B.W. and FROST, B.R. (1975): Chrome-spinel in progressive metamorphism - a preliminary analysis. Geochim. Cosmochim. Acta 39, 959-972.

EVANS, B.W. and TROMMSDORFF, V. (1970): Regional Metamorphism of Ultramafic Rocks in the Central Alps: Parageneses in the System $CaO-MgO-SiO_2-H_2O$. Schweiz. Mineral. Petrogr. Mitt. 50, 481-492.

EVANS, B.W., TROMMSDORFF, V., GOLES, G.G. (1981): Geochemistry of High-Grade Eclogites and Metarodingites from the Central Alps. Contrib. Mineral. Petrol. 76, 301-311.

FISCH, H.R. (1988): Petrographie und Strukturen der Tonalen Zone und der Iorio-Intrusiva nördlich des Passo San Iorio. Dipl. thesis Nr. 339 Geol. Inst. ETH Zürich.

FISCH, H.R. (1989): Zur Kinematik der südlichen Steilzone der Zentralalpen E von Bellinzona. Schweiz. Mineral. Petrogr. Mitt. 69 (this volume).

FROST, B.R. (1988): A review of graphite-sulfide-oxide-silicate equilibria in metamorphic rocks. Rend. Soc. Ital. Min. Pet. 34, 25-44.

FUMASOLI, M.W. (1974): Geologie des Gebietes nördlich und südlich der Iorio-Tonale Linie im Westen von Gravedona (Como, Italien); Diss. Nr. 194 (Neue Folge), Univ. Zürich.

GHENT, E.D. (1976): Plagioclase-garnet-Al_2SiO_5-quartz: A potential geobarometer-geothermometer. Amer. Mineral. 61, 710-714.

GULSON, B.L. and KROGH, T.E. (1973): Old Lead Components in the Young Bergell Massif, South-East Swiss Alps. Contrib. Mineral. Petrol. 40, 239-252.

HAMMARSTROM, J.M. and ZEN, E-AN (1986): Aluminium in hornblende: An empirical igneous geobarometer. Amer. Mineral. 71, 1297-1313.

HEITZMANN, P. (1975): Zur Metamorphose und Tektonik im südöstlichen Teil der Lepontinischen Alpen (Prov. Como, Italia). Schweiz. Mineral. Petrogr. Mitt. 55, 467-522.

HEITZMANN, P. (1987a): Calcite mylonites in the Central Alpine "root zone". Tectonophysics 135, 207-215.

HEITZMANN, P. (1987b): Evidence of late oligocene/early miocene backthrusting in the central alpine "root zone". Geodinamica Acta 1, 183-192.

HOLDAWAY, M.J. (1971): Stability of andalusite and the aluminium silicate phase diagram. Am. J. Sci. 271, 97-231.

HUNZIKER, J.C. (1966): Zur Geologie und Geochemie des Gebietes zwischen Valle Antigorio (Prov. di Novara) und Valle di Campo (Kt. Tessin). Schweiz. Mineral. Petrogr. Mitt. 46, 473-552.

HURFORD, A.J. (1986): Cooling and uplift patterns in the Lepontine Alps South Central Switzerland and an age of vertical movement on the Insubric fault line. Contrib. Mineral. Petrol. 92, 413-427.

JÄGER, E. (1973): Die alpine Orogenese im Lichte der radiometrischen Altersbestimmung. Eclogae Geol. Helv. 63, 163-172.

JENKINS, D.M. and CHERNOSKY, J.V. (1986): Phase equilibria and crystallochemical properties of Mg-chlorite. Am. Min. 71, 924-936.

KNOBLAUCH, P. and REINHARD, M. (1939): Erläuterungen zur geologischen Karte, Blatt Nr. 516, Iorio; Kommissions-Verlag A. Francke AG, Bern.

KNOBLAUCH, P., REINHARD, M., KÜNDIG, E. (1939): Blatt 516, Iorio; Geol. Atlas der Schweiz.

KOZIOL, A.M. and NEWTON, R.C. (1988): Redetermination of the anorthite breakdown reaction and improvement of the plagioclase-garnet-Al_2SiO_5-quartz geobarometer. Amer. Mineral. 73, 216-223.

MILNES, A.G. (1973): Structural reinterpretation of the classic Simplon tunnel section of the Central Alps. Bull. Geol. Soc. Am. 84, 269-274.

MILNES, A.G. (1974): Structure of the Pennine Zone (Central Alps): A New Working Hyothesis. Geol. Soc. Am. Bull. 85, 1727-1732.

NEWTON, R.C. and HASSELTON, H.T. (1981): Thermodynamics of the garnet-plagioclase-Al_2SiO_5-quartz geobarometer. In R.C. Newton, A. Navrotsky and B.J. Wood, Eds., Advances in physical geochemistry, vol. 1, 131-147. Springer-Verlag, New York.

NISBET, E.G., DIETRICH, V., ESENWEIN, A. (1979): Routine trace element determination in silicate minerals and rocks by X-ray fluorescence. Fortschr. Miner. 57, 264-279.

OHNENSTETTER, M. and OHNENSTETTER, D. (1980): Comparison between Corsican albitites and oceanic plagiogranites. Arch. Sci. 33, 201-221.

PEARCE, J.A. and CANN, J.R. (1973): Tectonic setting of basic volcanic rocks determining using trace element analyses. Earth Planet Sci. Lett. 19, 290-300.

PFEIFER, H.R. (1987): A model for fluids in metamorphosed ultramafic rocks: IV. Metasomatic veins in metaharzburgites of Cima di Gagnone, Valle Verzasca, Switzerland. In H.C. Helgeson, Ed., Chemical Transport in Metasomatic Processes, 591-632. D. Reidel Publishing Company.

PFEIFER, H.R, COLOMBI, A., GANGUIN, J. (1989): Zermatt-Saas and Antrona zone: A petrographic and geochemical comparison of polymetamorphic ophiolites of the West-Central Alps. Schweiz. Mineral. Petrogr. Mitt. 69, in press.

REUSSER, C.E. (1987): Phasenbeziehungen im Tonalit der Bergeller Intrusion (GR/Schweiz; Provinz Sondrio/Italien). Diss. Nr. 8329, ETH Zürich.

RICE, J.M. (1983): Metamorphism of Rodingites: Part I. Phase relations in a portion of the system $CaO-MgO-Al_2O_3-SiO_2-CO_2-H_2O$. Amer. J. Sci. 283-A, Orville Volume, 121-150.

RICHARDSON, S.W., GILBERT, M.C., BELL, P.M. (1969): Experimental determination of kyanite-andalusite and andalusite-sillimanite equilibria; the aluminium silicate triple point. Amer. Jour. Sci. 267, 259-272.

RIEDEL, W. (1929): Zur Mechanik geologischer Brucherscheinungen. Zent. Min. Geol. Pal. 1929, 354-368.

SCHMID, S.M., ZINGG, A., HANDY, M. (1987): The Kinematics of Movements along the Insubrik Line and the Emplacement of the Ivrea Zone. Tectonophysics 135, 47-66.

SCHMID, S.M., AEBLI, H.R., HELLER, F., ZINGG, A. (1989): The role of the Periadriatic Line in the tectonic evolution of the Alps. In: M.P. Coward, D. Dietrich, R.G. Park, Ed.; Geol. Soc. London, Special publication, No. 45, 153-171.

SCHMIDT, C. (1908): Über die Geologie des Simplongebietes und die Tektonik der Schweizeralpen. Eclogae Geol. Helv. IX, 484-584.

SCHMIDT, M.W. (1988): Petrographie der Ganna Rossa und Strukturen in der Zone von Bellinzona. Diploma thesis Nr. 329 Geol. Inst. ETH Zürich.

SHERVAIS, J.W. (1982): Ti-V plots and the petrogenesis of modern and ophiolitic lavas. Earth Planet. Sci. Lett 59, 101-118.

STILLE, P. and TATSUMOTO, M. (1985): Precambrian tholeiitic-dacitic rock-suites and Cambrian ultramafic rocks in the Pennine nappe system of the Alps: Evidence from Sm-Nd isotopes and rare earth elements. Contrib. Mineral. Petrol. 89, 184-192.

STILLE, P. (1987): Geochemische Aspekte der Krustenevolution im Zentral- und Südalpinen Raum. Habilitationsschrift, Inst. Kristall. Petr. ETH Zürich.

THOMPSON, A.B. (1975): Mineral reactions in pelitic rocks: II. Calculation of some P-T-X(Fe-Mg) phase relations. Amer. J. Sci. 276, 425-454.

TROMMSDORFF, V. and EVANS, B.W. (1979): Excursion to Alpe Albion (East of Bellinzona). Excursion of symposium on tectonic inclusions and associated rocks in serpentinites, Genève, Sept. 1979 (unpublished).

TROMMSDORFF, V. and EVANS, B.W. (1974): Alpine Metamorphism of Peridotitic Rocks. Schweiz. Mineral. Petrogr. Mitt. 54, 333-352.

VOGLER, W.S. and VOLL, G. (1976): Fabrics and Metamorphism for Tonalite, Granitic Augengneis and Tonale Series at the S-Margin of the Swiss Alps, E of Bellinzona. Schweiz. Mineral. Petrogr. Mitt. 56, 635-640.

VOGLER, W.S. and VOLL, G. (1981): Deformation and Metamorphism at the South-Margin of the Alps, East of Bellinzona, Switzerland. Geol. Rdsch. 70, 1232-1262.

WEBER, J. (1957): Petrographische und geologische Untersuchung des Tonalitzuges von Melirolo-Sorico zwischen Tessintal und Comersee. Schweiz. Mineral. Petrogr. Mitt. 37, 267-397.

WIELAND, H. (1966): Zur Geologie und Petrographie der Valle Isorno (Novara, Italia). Schweiz. Mineral. Petrogr. Mitt. 46, 189-303.